Christ Church Grammar School

Science Department
Year 11 Physics

Semester 1 Examination, 2021

Question/Answer booklet

PHYSICS UNIT 1

SECTION ONE

SHORT ANSWER

Fix student label here

SOLUTIONS

Time allowed for this paper

Reading time before commencing work: ten minutes
Working time for paper: two hours

Materials required/recommended for this paper

To be provided by the supervisor

Three Question/Answer booklets
Formulae and Data booklet

To be provided by the candidate

Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, correction fluid/tape, eraser, ruler, highlighters

Special items: up to three calculators, which do not have the capacity to create or store programmes or text, are permitted in this ATAR course examination, drawing templates, drawing compass and a protractor.

Important note to candidates

No other items may be taken into the examination room. It is your responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available		Percentage of exam	Percentage achieved
Section One: Short Answer	9	9	50		56	30	
Section Two: Problem Solving	6	6	80		78	50	
Section Three: Comprehension	1	1	20		17	20	
						100	

Instructions to candidates

1. The rules of conduct of Christ Church Grammar School assessments are detailed in the Reporting and Assessment Policy. Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer booklet preferably using a blue/black pen. Do not use erasable or gel pens.

3. You must be careful to confine your responses to the specific questions asked and to follow any instructions that are specific to a particular question.

4. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

5. Information for questions has been repeated on the removable Information Booklet which has been inserted inside the front cover of this booklet so that you can refer more easily to it while answering the questions. Do not write your answers in the Information Booklet.

6. Provide all answers to three significant figures unless otherwise instructed.

Section One: Short Response **30% (57 marks)**

This section has nine **(9)** questions. Answer **all** questions. Write your answers in the space provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to three significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working or reasoning clearly. Give final answers to two significant figures and include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 50 minutes.

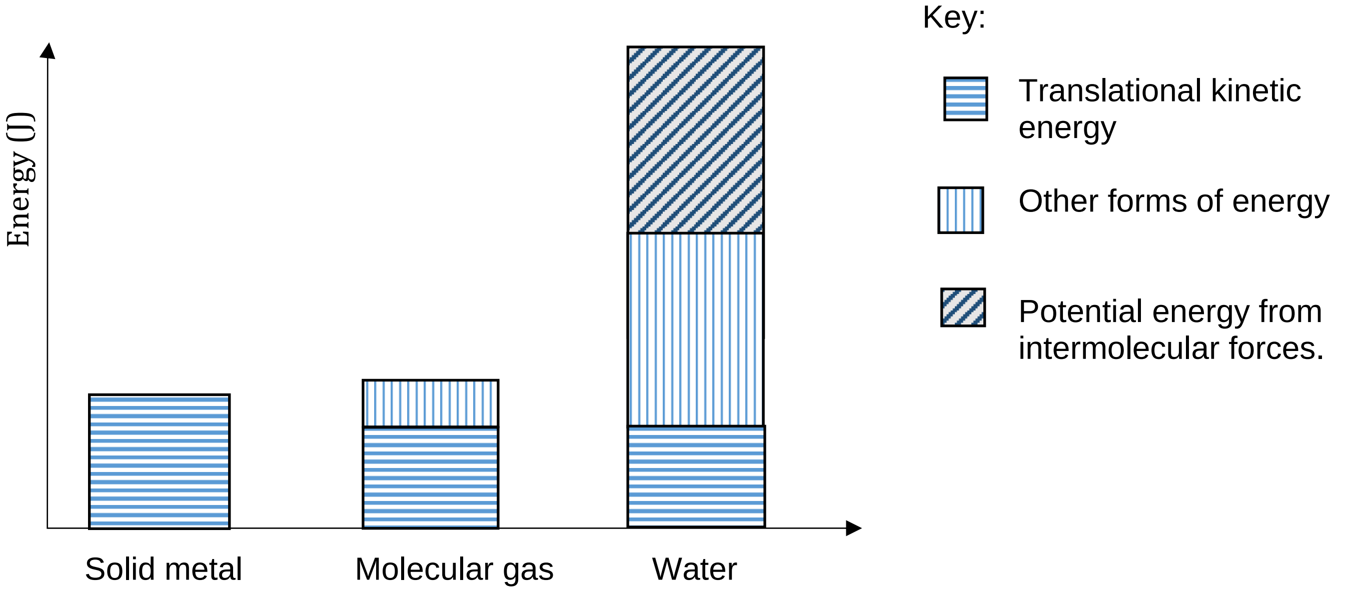
Question 1 **(5 marks)**

A hockey player attains a high metabolic rate during a game and much of the excess heat generated must be lost by sweating. During such a game, he develops excess heat at the rate of 568 joules per second. If 90.0 % of this heat must be lost by sweating, calculate the mass of sweat produced in a 25.0 minute session. Assume all of the sweat evaporates and the latent heat of vaporisation of sweat is 2.26×10^6 J kg^{-1}.

Description	Total
Q = P x t x ɛ/100 = 568 x (25 x 60) x 0.9	1
= 766,800 J	1
$Q = mL_v$, $m = Q/L_v$	1
= 766,800 / (2.26×10^6)	1
= 0.339 Kg	1
Total	**5**
Generally well done. Common mistakes were forgetting to reduce the useful energy to 90% of the total. And there were a few conversion mistakes when converting minutes to seconds	

Question 2 **(5 marks)**

Consider 3 systems below containing the same mass but different substances as listed on the chart below.



(a) Complete the table below by comparing the different features of each system shown above. Use the words "equal, higher, lower or medium" in the spaces below.

(2 marks)

Feature	Solid metal	Molecular gas	Water
Temperature of system	higher	equal	Equal
Internal energy	lower	medium	Higher

Description	Total
1 mark for each "row" correct.	2
Total	**2**
Generally well done.	

(b) Explain why the temperature of the water system differs to that of the solid metal system, even though it contains more kinetic energy.

(3 marks)

Description	Total
Temperature is a measure of the mean translational velocities of particles in a substance.	1
Water has other forms of kinetic energy; rotational and vibrational	1
So it contains more kinetic energy but is at a lower temperature.	1
Total	**3**
There were very poor definitions of temperature with key words absent, leading to half-marks being awarded. This question did not require mention of specific heat capacity (which is related to the features of waters graph) but rather that temperature could only measure translational energy, not other forms such as rotational of vibrational energy between bonds.	

Question 3 **(7 marks)**

During an alpha decay of americium-241 mass is converted to energy which is shared as kinetic energy amongst the daughter particle and the alpha particle.

(a) Write an equation for this reaction.

(1 mark)

Description	Total
$^{241}_{95}Am \rightarrow {}^{237}_{93}Np + {}^{4}_{2}\alpha$	1
Total	**1**
No errors at all.	

(b) Calculate the mass defect of the event in kilograms. Hint; you will not require all of the masses in the table below.

(4 marks)

Particle	**Atomic mass (u)**
Americium-241	241.05683
Americium-237	237.05000
Neptunium-237	237.04817
Neptunium-241	241.05825
Alpha	4.00150
Electron	0.00054857
Helium	4.002602

Description	Total
m.d. = m(Am-241) – m(Np-237) – m(alpha) – 2x m(e^-) OR = m(Am-241) – m(Np-237) – m(Helium)	1
= 241.05683 – 237.04817 – 4.002602	1
= 006058 u	1
x1.66 x10^{-27} = 1.01 x10^{-29} kg	1
Total	**4**
Majority of students forgot to realise that the daughter nucleus had an extra 2 electrons, so the mass of the electrons needed to be considered.	

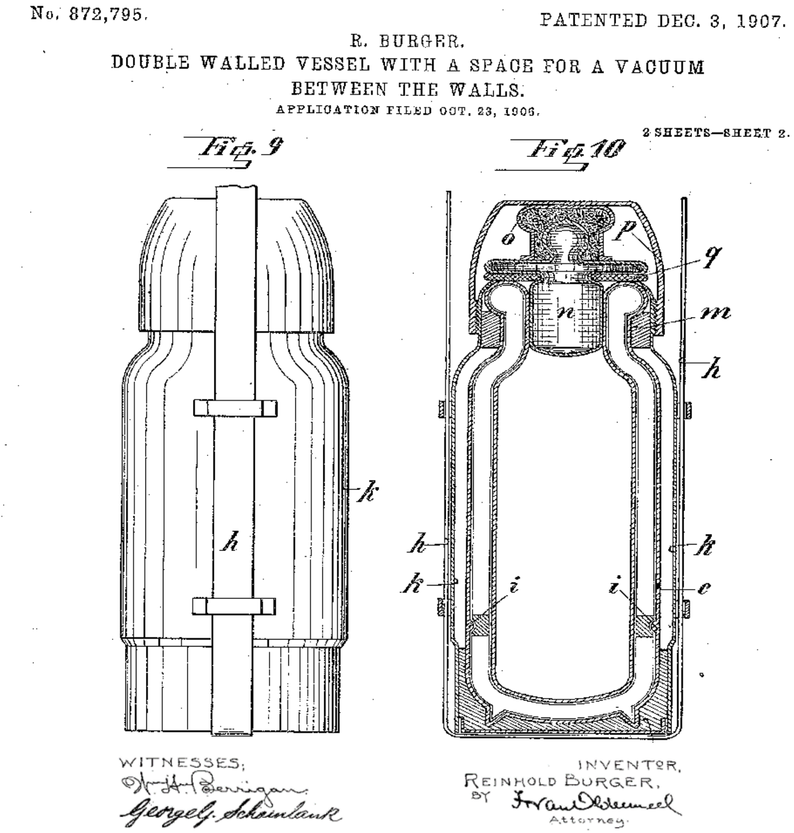
(c) State and explain which of the isotopes, parent or daughter, is likely to have the highest binding energy per nucleon. You do not require a calculation.

(2 marks)

Description	Total
The daughter nucleon	1
As its mass number has moved closer to the “iron peak” of nuclear stability.	1
Total	**2**
Poorly done. Many students got mark 1 incorrect and even more were unable to explain about the Iron peak of nuclear stability. Many students mentioned a reduction in mass number which is not correct (when considering all elements lighter than Fe-56.	

Question 4 **(6 marks)**

The following diagram shows the original patent for a vacuum thermos flask.



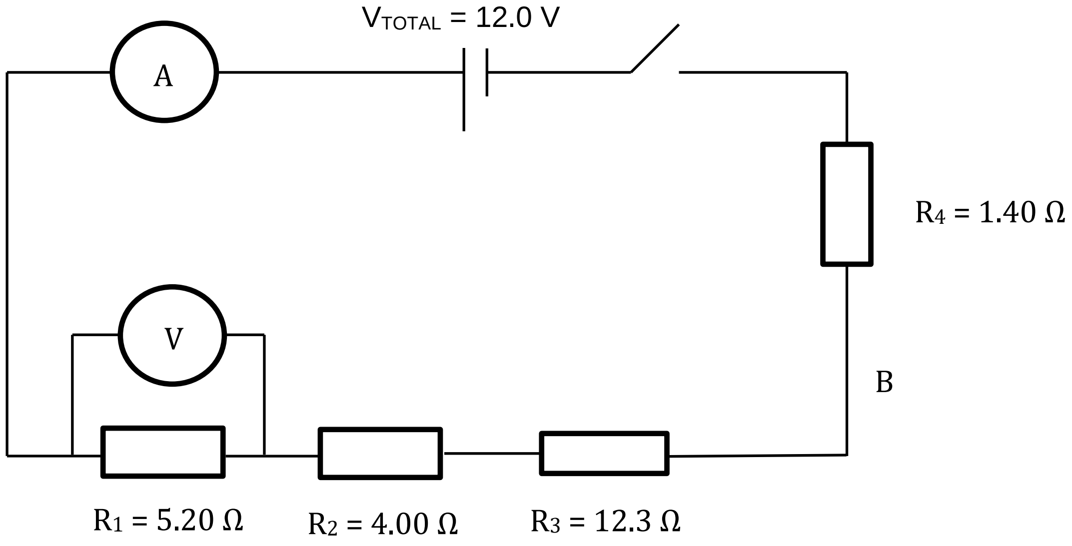
n :plastic stopper
i :foam sponges
p : plastic cup
q : rubber seal
k : evacuated space
h : white walled plastic
c : silvered inner liner

State and explain three design features that reduce heat loss. Your response must include all three heat transfer processes.

Description	Total
n or p: traps air in the thermos. Still air is an insulator	1
and prevents transfer of heat **away** from the flask by convection	1
k: Evacuated space has no molecules/vacuum	1
and prevents heat loss via convection and conduction.	1
h: white walled surface has a lower emissivity	1
and reduces the rate of radiation emitted from the thermos	1
c: silvered inner reflecting surface. Reflects radiated infrared radiation back towards body	1
To reduce rate of heat loss.	1
i: foam sponges are made of a non-metal which is thermally insulating	1
which reduces the rate of heat lost via conduction	1
Total	**6**
Generally well done, a few incorrect words made some statements false. Need to be accurate with terminology	

Question 5 **(8 marks)**

Consider the series circuit below:



(a) Calculate the reading in the ammeter.

(4 marks)

Description	Total
R_T = 5.2 + 4 + 12.3 + 1.40	1
= 22.9 Ω	1
$V = I_T R_T$ $I_T = V / R_T$ = 12.0 / 22.9	1
= 0.524 A	1
Total	**4**
Generally well done. Alarmingly, many students decided to express their current to 2 significant figures which is incorrect.	

(b) Calculate the reading in the voltmeter.

(2 marks)

Description	Total
$V_{R1} = I_T R_1$	1
= 0.524 (5.2) = 2.72 V	1
Total	**2**
Generally well done.	

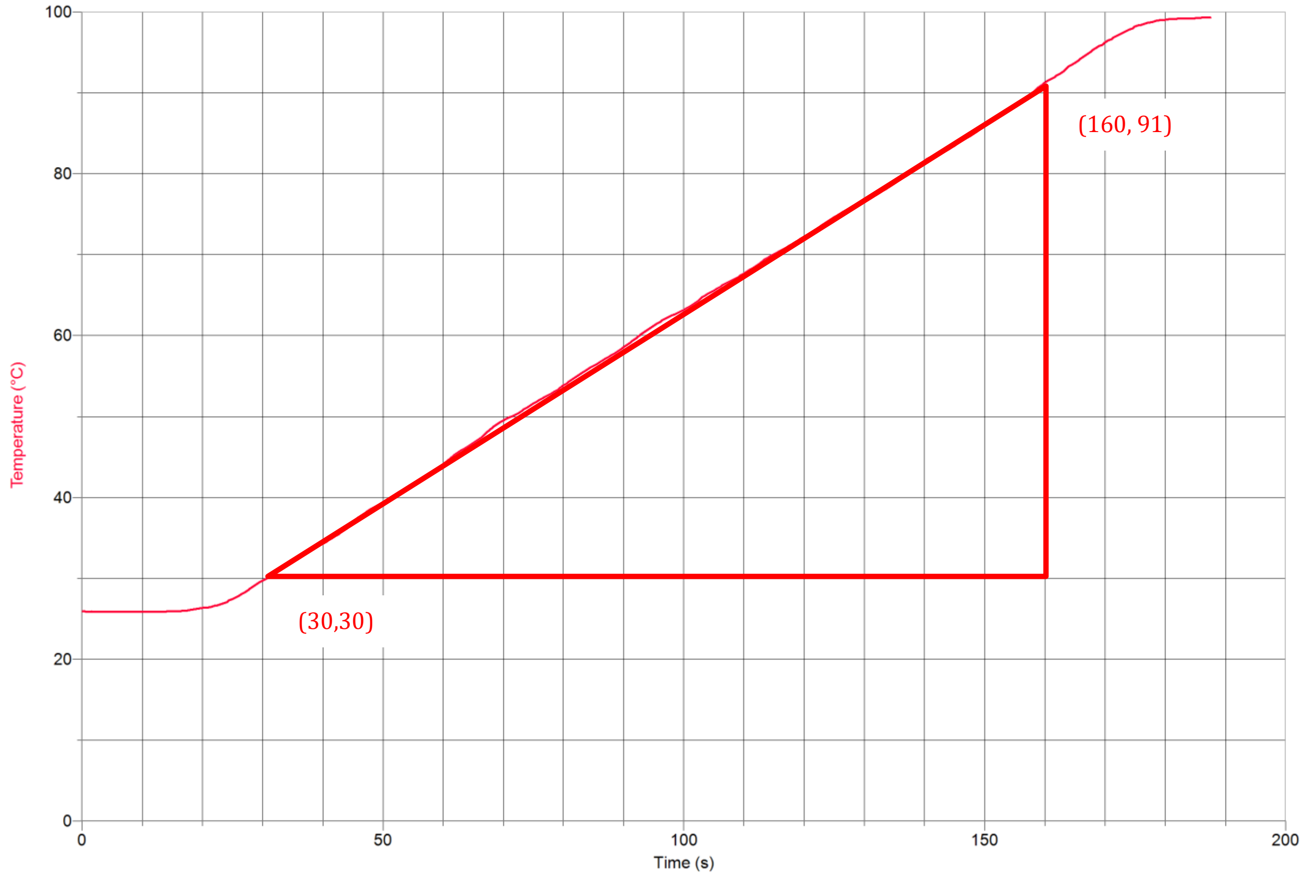
(c) State and explain what the ammeter would read if it were placed at point B.

(2 marks)

Description	Total
The same reading (0.524 A)	1
Current is equal throughout all sections of a series circuit.	1
Total	**2**
Generally well done.	

Question 6 **(6 marks)**

The following graph shows how the temperature of 500 grams of water varies with time as it is heated with an electrical heating element.



(a) Calculate the gradient of the graph for the period of time where the temperature is changing.

(3 marks)

Description	Total
$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{91 - 30}{160 - 30}$	1
= 0.47	1
°C s^{-1} (units present)	1
Total	**3**
Generally well done. A few students omitted units. All physics graphs require units for their gradients.	

(b) Use the gradient to calculate the effective power of the heating element.

(3 marks)

Description	Total
$P = \Delta Q / \Delta t = mc(\Delta T/\Delta t)$, gradient = $\Delta T/\Delta t$	1
= 0.500 (4180) 0.47	1
= 980 W	1
Total	**3**
Many students opted to complete in two steps; finding Q and then dividing by a time interval. The question explicitly asks to use the gradient, so many students did not use the value obtained in (a)	

Question 7 **(4 marks)**

A 0.900 kg aluminium tray is removed from a hot industrial furnace and 245 grams of water at 21.0 °C is immediately placed on it. It was discovered after reaching thermal equilibrium of 36.5 °C that 25 grams of water had vaporised and turned to steam at 100 °C, thus leaving the system and that the remaining 220 grams reached the equilibrium temperature. Assuming no other heat losses from the system, calculate the initial temperature of the aluminium tray.

$C_{AL} = 900\ J\ kg^{-1}\ K^{-1}$
$C_{water} = 4180\ J\ kg^{-1}\ K^{-1}$

Description	Total
$Q_G + Q_L = 0$ $m_W c_W \Delta T + mL_v + m_W c_W \Delta T + m_A c_A \Delta T_A = 0$	1
$0.025(4180)(79) + 0.025(22.6\times10^6) + 0.22(4180)(15.5) + 0.9(900)(36.5 - T_i) = 0$	1
8255.5 + 56,500 + 14,254 + 29,565 – $810T_i$ = 0 810 T_i = 108574.5	1
T_i = 134 °C	1
Total	**4**
Common errors included not separating the water for heat gained. 25 grams needed to be heated to 100 degrees and then vaporised. The remaining 220 grams was only heated to 36.5 degrees. Silly arithmetic errors was also common.	

Question 8 **(8 marks)**

There are similarities and differences in the nature and properties of alpha beta and gamma radiation.

(a) Describe what is occurring in the nucleus when a radionuclide undergoes beta + decay.
(2 marks)

Description	Total
a proton turns into a neutron	1
and emits a beta particle, an neutrino and energy	1
Total	**2**
Many students neglected to include the antineutrino	

After an alpha or a beta emission, the atom of the new isotope is often left in a *metastable* state.

(b) Explain what is meant by metastable and state what the new isotope must eventually do.
(2 marks)

Description	Total
After a beta/alpha decay, the arrangement of nucleons are still in a high state of energy / arrangement	1
The isotope atom will quickly reassemble the nucleons and emit a high energy gamma ray	1
Total	**2**
This question was done quite poorly; indicating that many students did not know the process of gamma emission.	

(c) Compare the properties of alpha, beta and gamma radiation by completing the table below.
(4 marks)

	Emission speeds (Low medium high)	**Penetrating ability** (Low medium high)	**Charge**	**Mass (kg)**
Alpha	Low	Low	+2	6.64×10^{-27} kg
Beta	Medium	Medium	+/- 1	9.11×10^{-31}
Gamma	high	high	0	None

Description	**Total**
1 mark for each correct column	1
Total	**1**
Some students made the mistake of putting the mass of a proton (1.67×10^{-27} kg) instead of the mass of an electron for beta. Also, many students flipped the order of the emission speeds of penetrating ability.	

Question 9 **(7 marks)**

Determine each of the unknown particles in the nuclear equations below. If the particle is an isotope, provide its full name.

(a) $^{45}_{20}Ca \rightarrow ^{45}_{21}Sc + ^{-1}_{0}\beta + ^{0}_{0}\bar{\upsilon}$ particle: beta negative particle

(b) $^{11}_{5}B + ^{4}_{2}\alpha \rightarrow ^{14}_{7}N + ^{1}_{0}n$ particle: neutron

(c) $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{140}_{38}Sr + ^{94}_{54}Xe + 2^{1}_{0}n$

particle: Xenon - 94

(d) $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{1}_{0}n + ^{4}_{2}He$ particle: Helium - 4

Description	Total
1 mark for each	1
Total	**4**
Done well, though a few students incorrectly calculated the mass number of Xenon and some did not fully name the isotope xenon-94	

There are physical limitations that prevent the particle interaction in (d) from occurring.

(e) Describe why the limitations occur and how they are overcome in practical applications of the particle interaction.

(3 marks)

Description	Total
The positive charges of the nucleons causes the atoms to experience a repulsive force	1
The atoms must be brought together under incredibly high temperature and pressure	1
In order for the nucleons to come into contact and undergo fusion	1
Total	**3**
Generally well done, though some students focused on the alpha emission and tried to discuss alpha decay, rather than nuclear fusion and physical limitations that inhibit the process.	

End of Section One

Question 10 **(15 marks)**

The gas hot water system breaks in a person's home and they wish to pour a hot bath. They fill a bathtub with 125 kg of water at 24.0 °C. They decide to use an electric kettle that can boil 2.00 kg of 24.0 °C water at a time and pour this boiling water into the bathtub to raise its temperature. The kettle is rated at 2400 W and is supplied by 240 V AC power.

(a) Calculate the electrical resistance of the kettle when it is operating. (3 marks)

Description	Total
P = I V, I = P / V , R = V / I , R = V^2 / P	1
= 240^2 / 2400	1
= 24.0 Ω	1
Total	**3**
Generally well done. Marks were lost here for providing the incorrect number of SF.	

(b) Calculate the charge that flows through the kettle element in a time of 45.0 seconds. (4 marks)

Description	Total
I = P / V = 2400 / 240	1
= 10.0 A	1
Q = I.t = 10.0 x 45	1
= 4.50 x 10^2 C	1
Total	**4**
A number of students calculated the current in part (a) but received full marks for part (b). Furthermore, some students continued on to find the number of electrons which was not asked for. In general, students lost marks for arithmetic errors.	

(c) Calculate the time taken for the kettle to bring the water to its boiling point.

(3 marks)

Description	Total
$t = Q / P = mc\Delta T / P$	1
$= 2(4180)(100-24) / 2400$	1
$= 265$ s	1
Total	**3**
Generally well done. A number of students providing incorrect SF or arithmetic errors	

The person decides that they only have the patience to boil 5 kettles of water before they have had enough and want to have their bath.

(d) Calculate the final temperature of the bathtub.

(4 marks)

Description	Total
$Q_g + Q_L = 0$ $mc\Delta T + mc\Delta T = 0$	1
$125(4180)(T_f – 24.0) + 5x2(4180)(T_f – 100) = 0$	1
$522{,}500\ T_f – 12{,}540{,}000 + 41{,}800\ T_f - 4{,}180{,}000 = 0$ $564{,}300\ T_f = 16{,}720{,}000$	1
$T_f = 29.6$ °C	1
Total	**4**
Common mistakes included using 115kg as the mass of water in the bath and only 2kg for mass of water in the kettle. Generally well done though and follow through marks were awarded.	

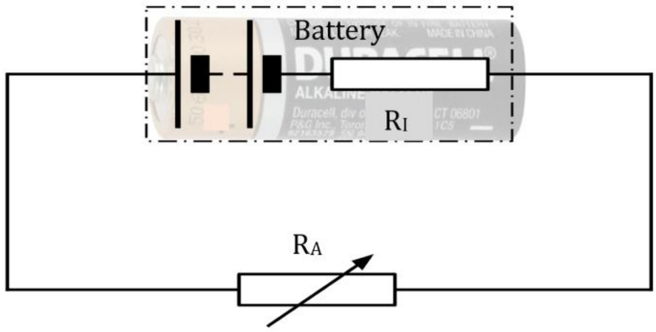
(e) State one valid assumption about any of the calculations you have made in this question.

(1 mark)

Description	Total
No heat lost from bathtub to surroundings as it was being filled with boiling water water did not vaporize/evaporate while/prior to being transferred system is perfectly insulated All heat is transferred to cold water	1
Total	**1**
Generally well done.	

Question 11 **(14 marks)**

A cell in a circuit supplies electrical energy to other components of the circuit. If the cell has internal resistance, some of the electrical energy produced is wasted due to heating inside the cell. The internal resistance in the cell can be treated as a resistor that is in series with rest of the circuit. As the battery's internal resistance increases, it has said to have gone "flat", as it can no longer provide a suitable EMF (total voltage provided) to the circuit.



An interesting observation is that as the current through the circuit increases, the EMF provided by the battery decreases. Consider a cell connected to a resistance R_A. The cell's EMF is E and its internal resistance is R_I. Given Ohm's Law, current can be expressed as:

$E = IR_A + IR_I$ So: $IR_A = -IR_I + E.$

Or: $V = -R_I.I + E.$

Students conduct an experiment to test the internal resistance of two 1.5 Volt batteries to determine if they are flat or not. They use a variable resistor to vary the total resistance of the circuit and obtain the following voltages (V) across the resistor as provided in the table.

	Voltage (V)	
Current (A)	Battery 1	Battery 2
0.00	1.50	1.50
0.20	1.32	1.45
0.40	1.12	1.40
0.60	0.93	1.36
0.80	0.73	1.32
1.00	0.55	1.25

(a) On the graph on the following page, plot a graph of Voltage vs Current for both batteries on the same set of axes. A spare grid is provided on the end of this Question/Answer booklet. If you need to use it, cross out this attempt and clearly indicate that you have redrawn it on the spare page.

(5 marks)

(b) Calculate the gradient of both graphs.

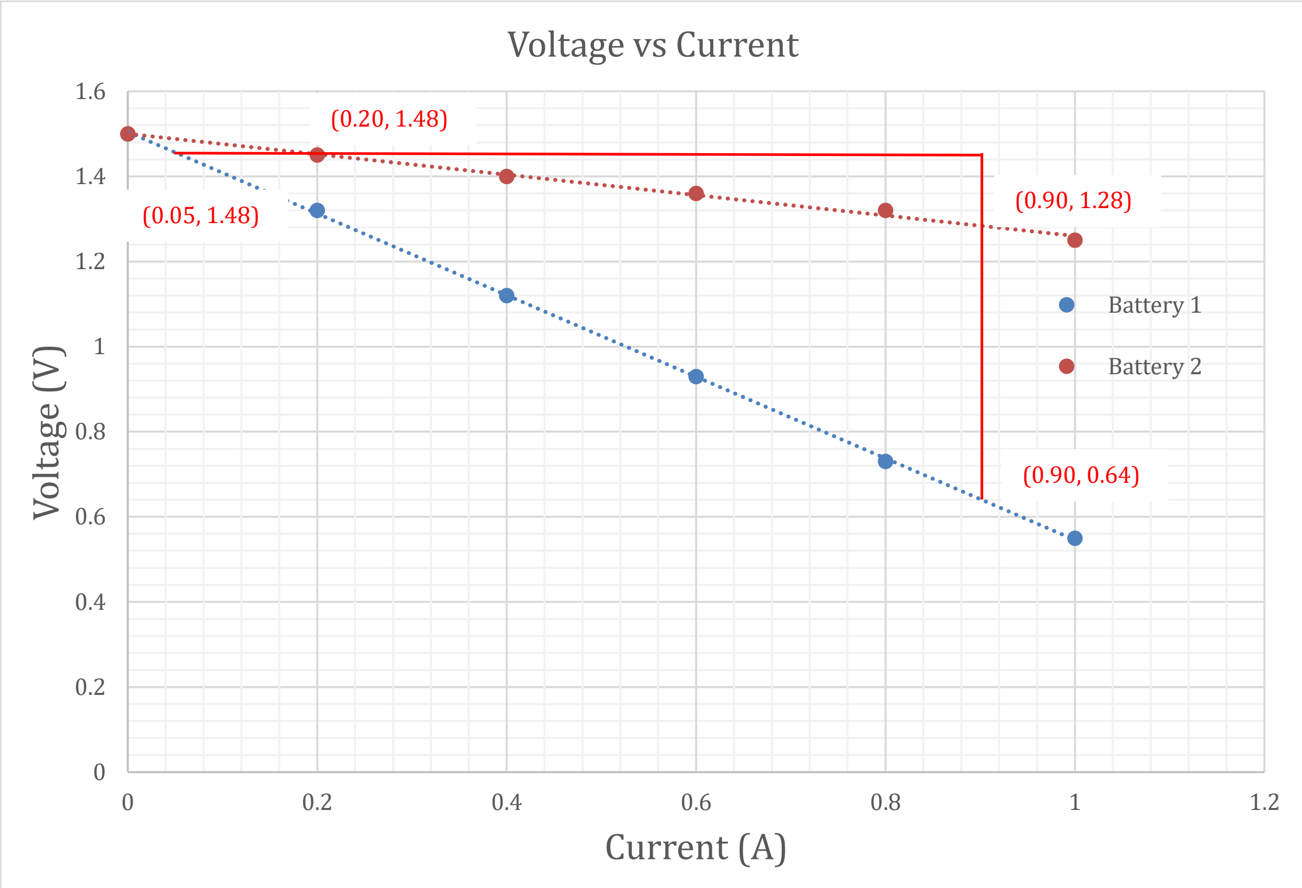
(4 marks)

Description	Total
$m_1 = \frac{y_2 - y_1}{x_2 - x_1} = \frac{1.48 - 0.64}{0.90 - 0.04}$ Battery 1	1
= -0.96	1
$m2 = \frac{y_2 - y_1}{x_2 - x_1} = \frac{1.48 - 1.28}{0.90 - 0.20}$ Battery 2	1
= -0.25	1
Total	**4**
Students lost marks here for not including the negative or not including sufficient working.	

(c) Hence, determine the internal resistance of both batteries and state which battery is 'flatter'.

(2 marks)

Description	Total
$R_{Internal}$ = - gradient $R_1 = 0.95\ \Omega$ $R_2 = 0.25\ \Omega$	1
Since B1 has a greater internal resistance, it is "flatter"	1
Total	**2**
Many students failed to make a link between the internal resistance and the gradient which meant that they lost marks.	



Description	Total
correct orientation of axes	1
correct labelling of axes including units and Title.	1
accurate plotting	1
key provided identifying each data series.	1
line of best fit (LOBF)	1
Total	**5**
Generally well done.	

(d) Explain why testing the voltage across a flat 1.50 V battery with a voltmeter might display a voltage of 1.50 V even though it is flat.

(3 marks)

Description	Total
When there is no current flowing through the battery,	1
there is no voltage drop across the internal resistance.	1
So V = E and the reading will display 1.50 V	1
Total	**3**
This was not done very well. Students needed to make the link between emf and voltage via the equation provided.	

Question 12 **(13 marks)**

Radon-222 (half-life 3.83 days) is a naturally occurring inert gaseous isotope of radon that forms from the alpha decay of radium-226 (half-life 1.6 × 10^3 years). Radium-226 is found in many rocks and building materials. Because radon-222 is a gas and its decay releases tissue-damaging radiation, it can cause lung cancer when inhaled into the lungs over a prolonged period

(a) Write the equation for the alpha decay of radium-226 to radon-222.

(2 marks)

Description	Total
$^{226}_{88}Ra \rightarrow\ ^{222}_{86}Rn + ^{4}_{2}\alpha$	
All particles correctly identified	1
Mass number and atomic number balanced.	1
Total	**2**
Generally well done.	

(b) Radon-222 also undergoes alpha decay. Explain why these alpha particles are so much more dangerous to humans than those released by the parent radium.

(3 marks)

Description	Total
Radium exists in rocks which will not come into contact with people's lungs	1
Radon is a gas which can be inhaled	1
meaning the alpha particles can damage the fine blood vessels in the lungs.	1
Total	**3**
Generally well done.	

A sample of radon-222 was measured to have an initial activity of 1.40 kBq.

(c) Calculate the activity of the sample 2.00 weeks later.

(3 marks)

Description	Total
$A = A_0(1/2)^{t / t1/2}$	1
$= 1.40 \text{ x} 10^3\ (1/2)^{14 / 3.83}$	1
= 111 Bq	1
Total	**3**
Students lost marks here for not converting kBq to Bq. Furthermore, some students mixed A with A0.	

Consider a sample of radon that was trapped in a closed room. A 78.0 kg person stayed in the room for eight hours. In that time their lungs, of mass 2.40 kg absorbed energy released by alpha particles equal to 0.160 J.

(c) Determine the localised absorbed dose this person could receive.

(2 marks)

Description	Total
A.D. $= \frac{\text{Energy}}{\text{mass}} = \frac{0.160}{2.40}$	1
= 0.0667 Gy	1
Total	**2**
A common error was for students to use a mass of 78.0 kg, rather than 2.40 kg. A number of SF errors in this question as well.	

(d) Determine the maximum localised dose equivalent of this radiation.

(2 marks)

Description	Total
D.E. = A.D. x Q.F. = 0.0667 x 20	1
= 1.33 Sv	1
Total	**2**
Follow through marks were awarded here. A number of students did not provide enough working and were deducted marks.	

The table below describes the approximate physiological effects of different types of dose equivalents

Whole Body Dose (mSv)	**Effect**
0 – 100	No observable effect
100 – 1000	Slight to moderate decrease in white blood cell counts
350 - 500	Temporary Sterility women; men
1000- 2000	Significant reduction in blood cell counts, brief nausea and vomiting. Rarely fatal.
2000 – 5000	Radiation sickness - Nausea, vomiting, diarrhoea, hair loss, skin rashes, severe blood damage, bone marrow damaged, hemorrhage, fatalities.
Localised Dose	**Effect**
0 – 100	No observable effect
100 – 300	Decrease in red blood cell count. Inflammation of tissue
300 - 800	Damage to capillaries and smaller blood vessels.
1000- 2000	Significant hemorrhaging of large blood vessels. Significant tissue atrophy
2000 – 5000	Severe damage to tissues, major hemorrhaging, organ and tissue failure.

Table 1: Physiological Effects of Radiation on an Adult Human

(e) State the physiological effects that the person might receive after being in this room for 8 hours.

(1 marks)

Description	Total
Significant hemorrhaging of large blood vessels. Significant tissue atrophy	1
Total	**1**
Follow through marks were awarded if the answer in part (d) was incorrect. A common error was not to convert the answer in part (d) to mSv.	

Question 13 **(11 marks)**

A group of year 11 physics students are reminiscing about their Venture trip. On this trip they rugged up warmly wearing woolen jumpers and thermal underwear and used a *trangia* (methylated spirit camp stove) to cook their pasta dinner. For the particular camp stove used, only 35.0 % of the energy released in burning the fuel actually went in to heating the water in the pot on the stove.

(a) Calculate how much heat was required to raise the temperature of 0.750 kg of water from 15.0 °C to 100.0 °C.

(2 marks)

Description	Total
$Q = mc\Delta T$ $= 0.75(4180)(100-15)$	1
$= 266$ kJ	1
Total	**2**
Generally well done. A number of students added in another term for a phase change to steam. Students also included the efficiency in this part as well which was not required.	

0.250 kg of the water boiled away while the pasta was cooking, requiring a further 1,688 kJ of energy from the trangia.

(b) If 1.00 g of methylated spirit releases 46.0 kJ, calculate the mass of methylated spirit used in the cooking of dinner.

(3 marks)

Description	Total
$Q_{out} = 266 + 1688$ $= 1954$ kJ	1
$\frac{Q_{out}}{Q_{in}} = 0.35 = \frac{1954}{Q_{in}}$	1
$Q_{in} = 5582$ kJ / 46 = 121 g	1
Total	**3**
Students failed to convert kJ to J which affected their answer. Or, they didn't include the efficiency. Some students only included the efficiency in one term and not the other.	

(c) Explain how woolen clothing and thermal underwear helped keep the students warm.

(3 marks)

Description	Total
Thermal conductivity of clothing is low	1
Which reduces the rate of heat transfer from the body to the environmnent	1
Retaining body heat.	1
OR	
Wool contains pockets of trapped air	1
Still air is a very effective thermal insulator	1
Reducing heat transfer from the body	1
Total	**3**
Generally well done, although students need to practice writing word answers to include all three point above. Students were often not explicit enough with their information leading to missed marks.	

The students observe that in the morning after a cold night, a lot of dew (water) as fallen onto the surfaces of their *hootchies* (tent).

(d) Explain the physical process of how the water was able to appear on the hootchie.

(3 marks)

Description	Total
Water vapour exists in the air	1
As the air temperature drops overnight, the vapour transfers energy to the air	1
And condenses into a liquid, which falls onto the hootchie.	1
Total	**3**
Generally well done. Although, some students have a misconception that air turns into water which needs to be addressed.	

Question 14 **(12 marks)**

The data sheet for the radioisotope lead-210 is shown below:

RADIONUCLIDE SAFETY DATA SHEET
NUCLIDE: Pb-210/Bi-210/Po210 FORMS: SOLUBLE

PHYSICAL CHARACTERISTICS:
HALF-LIFE: 20.4 years TYPE DECAY: beta -, beta -, alpha (Pb, Bi and Po, respectively.)

Energies: beta - (Pb) 0.061 MeV, beta - (Bi) 1.16 MeV, alpha (Po) 5.35 MeV

Hazard category: C - level (low hazard): .0001mCi to 0.1 mCi
B - level (Moderate hazard): > 0.01 mCi to 1.0 mCi
A - level (High hazard): greater than 1.0 mCi

EXTERNAL RADIATION HAZARDS AND SHIELDING:
The external exposure hazard is from the Bi-210 beta particle (99%) with maximum energy of 1.16 MeV. The maximum range of these betas in various materials is as follows: Air ~100 inches, Water ~0.17 inches, Glass ~0.07 inches. The beta dose rate at 1 cm from 1 mCi (from the Bi-210 in equilibrium) is approximately 310,000 mrad/hr.

HAZARDS IF INTERNALLY DEPOSITED:
This is a highly radiotoxic material. The principal hazard from Pb-210 occurs if the material is allowed into one's body. The Campus Annual Limit of Intake (oral), based upon 10% of the dose limit to bone surfaces, is 0.054 uCi. The effective half-life in the body is 1200 days. The campus ALI for inhalation is 0.0025 microcuries also based upon dose to bone surfaces.

(a) Write the 3 separate nuclear equations for the decays of lead-210, bismuth-210 and polonium-210.

(3 marks)

Description	Total
${}^{210}_{82}Pb \rightarrow {}^{210}_{83}Bi + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$	1
${}^{210}_{83}Bi \rightarrow {}^{210}_{84}Po + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$	1
${}^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}\alpha$	1
Total	**3**
Students were deducted marks if the anti-neutrinos were not provided. Otherwise, generally well done.	

A curie (Ci) is another unit of radioactivity. Originally it was defined as the activity of 1 gram of radium-226. 1 Ci = 3.70×10^{10} Bq = 37.0 GBq.

(b) Calculate the activity range, in Bq, of hazard category C (low hazard)

(3 marks)

Description	Total
Range = 0.0001×10^{-3} to 0.1×10^{-3}	1
= 10^{-7} Ci to 10^{-4} Ci x 3.70×10^{10}	1
= 3.70×10^{3} to 3.70×10^{6} Bq	1
Total	**3**
Several students incorrectly used a term of 0.001, rather than 0.0001. Students also were deducted marks for not providing the correct numbers of SF	

(c) Explain why the external exposure hazard is from bismuth-210 and not the other two radioisotopes.

(2 marks)

Description	Total
Pb also emits a beta negative particle but at a much lower energy emission	1
Po emits an alpha particle which does not pose an external risk as it has a low penetration ability.	1
Total	**2**
Students needs to relate their answer to the other two radioisotopes. If this was not done, a maximum of 1 mark was awarded.	

The millirad (mrad) is a unit of absorbed radiation dose, defined as 1 milirad = 1.00×10^{-5} Gy.

(d) Calculate the dose equivalent if a scientist stood 1.00 cm from 1.00 mCi of Bi-210 for a time of 0.200 hours.

(4 marks)

Description	Total
A.D. = 310,000 x 1.00×10^{-5} = 3.10 Gy / hr.	1
x 0.2 hour = 0.62 Gy	1
D.E. = A.D. x Q.F. = 0.62 x 1	1
= 0.620 Sv	1
Total	**4**
Generally well done. Students lost marks for not providing sufficient working.	

Question 15 **(13 marks)**

Nuclear power reactors and nuclear weapons both involve the release of nuclear energy by inducing fission. Neutron capture in a nuclear reactor or weapon primarily occurs with slow-moving neutrons. The chain reaction that occurs in the nuclear reactor is a 'controlled' chain reaction. This contrasts with the 'uncontrolled' chain reaction which occurs when a nuclear weapon is detonated.

(a) Name the structure in the nuclear fission reactor that is responsible for 'controlling' the chain reaction. Explain how this structure achieves this.

(3 marks)

Description	Total
Control rods	1
Absorb emitted neutrons and prevent them from being captured by fissile nuclei	1
Hence reducing the criticality of the reactor.	1
Total	**3**
Students often missed the last mark. Criticality was needed to be mentioned in order to achieve this	

In a 'gun-type' nuclear bomb, prior to detonation, two sub-critical samples of the fissile material are separated at either end of a long tube inside the bomb (see below). The bomb is carried on a long-range missile and is detonated at a determined altitude above the target. Upon detonation, conventional explosives force the two sub-critical samples together and a massive explosion results.

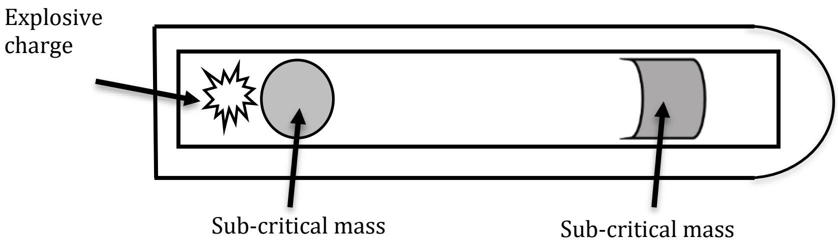


Figure 1: A basic diagram of a 'gun-type' nuclear bomb

(b) Define the terms 'critical mass' and 'sub-critical mass' and use them to explain the operation of the nuclear bomb described above.

(4 marks)

Description	Total
Critical mass the minimum mass of material required to produce 1 subsequence reaction from the first initial reaction. IE: Criticality of 1	1
Sub critical mass is one that is below critical mass	1
When the two sub critical masses are kept separate, they are unable to go super critical	1
When brought together in an explosion, the masses combine and become super critical	1
Total	**4**
A number of misconceptions about what critical mass is with relation to neutrons. Some students mentioned that it is the ratio of neutrons accepted to neutrons produced which is incorrect. This ratio does change with the mass of the sample.	

(c) State and explain one similarity and one difference (not mentioned in the first paragraph) of the processes occurring in a nuclear bomb and a nuclear power plant.

(4 marks)

Description		Total
Similarity: Both result in a mass defect	As mass is converted into energy as per $E = mc^2$	1
Both require enrichment of fuel	In order to produce a criticality > 1	1
Both require criticality > 1	in order to release substantial amounts of energy	1
Both have hazardous waste	due to the fission fragments being radioactive	1
Difference: Reactor requires criticality = 1 and bomb requires criticality >1	Bomb needs to release energy in a short period of time, whereas power plant releases it very gradually	1
Bomb requires higher enrichment	as criticality needs to be as large as possible	
	Total	**4**
A number of students mentioned things that were included in the first paragraph and therefore did not receive full marks.		

Aside from the initial immense pressure wave, one of the greater impacts of the bomb is the 'nuclear fallout'; fission fragment particulates that fall back down to the surface of the Earth. These fission fragments can remain highly radioactive for many decades after the blast and have ongoing adverse effects to organisms that inhabit that area.

(d) Explain why the fission fragments are radioactive and why they might remain active for many decades after the blast.

(3 marks)

Description	Total
Fissile nuclei, being quite heavy, have a large ratio of neutrons to protons	1
The fragments, being much smaller, have too large a ratio of neutrons to protons and are beta – emitters.	1
The are far from the zone of nuclear stability and often decay in a long decay series before becoming a stable isotope and this can take a very long period of time.	1
Total	**3**
This question was not done particularly well although, there were some excellent responses.	

End of Section Two

Question 16 **(17 marks)**

Clocks in rocks
(Adapted from Lead-Lead Dating – Wikipedia)

Planet Earth doesn't have a birth certificate to record its formation, which means scientists spent hundreds of years struggling to determine the age of the planet. So, just how old is Earth?

Earth is currently estimated to be 4.50 billion years old, plus or minus about 50 million years. Scientists have scoured the Earth searching for the oldest rocks to radiometrically date; using the relative amounts of known radioisotopes found in rocks. In northwestern Canada, they discovered rocks about 4.03 billion years old. Then, in Australia, they discovered minerals about 4.30 billion years old. Researchers know that rocks are continuously recycling, due to the rock cycle, so they continued to search for data elsewhere. Since it is thought the bodies in the solar system may have formed at similar times (in regions known as planetesimals), scientists analysed moon rocks collected during the moon landing and even meteorites that have crash-landed on Earth. Both of these materials dated to between 4.40 and 4.50 billion years (4.40 – 4.50 Gyr).

Radiometric dating is a technique which is used to date materials such as rocks, in which small traces of radioisotopes were introduced into the rock sample when they were formed. The method compares the abundance of a naturally occurring radioisotope or "parent isotope" within the material to the abundance of its decay products or "daughter isotope", which form at a known constant rate of decay. Many rocks contain various isotopes of uranium which can decay via different decay series to stable isotopes of lead.

There are two stable daughter isotopes of lead that result from the radioactive decay of uranium in nature; they are Pb-206 and Pb-207. These daughter isotopes are the final decay products of uranium radioactive decay series beginning from U-238 and U-235 respectively. Pb-204 is the only *non-radiogenic* lead isotope: a stable isotope with no parent material forming it, and it doesn't decay to be the parent of another material.

With the progress of time, the final decay product accumulates as the parent isotope decays at a constant rate. This shifts the ratio of radiogenic Pb versus non-radiogenic Pb-204 ($^{207}Pb/^{204}Pb$ or $^{206}Pb/^{204}Pb$) in favor of radiogenic Pb-206.

The following values for the isotopes are given below:

$^{238}U \rightarrow {}^{206}Pb$ $t_{1/2} = 4.47 \times 10^9$ years (4.47 Gyr)

$^{235}U \rightarrow {}^{207}Pb$ $t_{1/2} = 0.70 \times 10^9$ years (0.70 Gyr)

^{204}Pb $t_{1/2} = 0.00$ years (stable)

Providing the sample contains enough traces of all 3 isotopes of lead, this "Pb-Pb" dating method can be simplified to an equation that can be used to determine the time since the sample was formed.

(a) Calculate the percentage uncertainty of the age of the Earth.

(2 marks)

Description	Total
$\pm \frac{50}{4500} \times 100$	1
= $\pm$ 1.11 %	1
Total	**2**
Very well done. 2 or 3 significant figures were accepted for this. The front cover states you should use 3 sf unless specified otherwise, and 2 sf for estimates. The age is an estimate hence both options are OK.	

The equations used in radiometric dating are formed from 4 main assumptions:

1. ***The sample is "closed".***

With respect to parent and daughter, if any parent isotope leaks in or if any daughter isotope leaks out of the sample then the ratio will not reflect the age of the sample. This can be difficult in certain rock types: Uranium atoms are water soluble and can easily *leak out* of a crystal lattice if there is sufficient water present. Whereas its daughter isotope; Thorium is the opposite, not wanting to be in solution and preferring to remain in a crystal lattice, resisting quite strongly. Metamorphic rocks which are made under immense heat and pressure can affect the amount of parent and daughter isotopes present in the sample throughout the eons of time.

2. ***The half-life of the parent-daughter pairs are constant.***

This is well established across the scientific community. And most radio-isotopes half-lives are now known to a high degree of precision.

3. ***The age of the rock is old enough such that there are enough daughter isotopes to be detected within acceptable error.***

Some igneous rocks have been formed from volcanic and tectonic activity too recently and cannot be used. As well, Sedimentary rocks contain too many varieties of rock types and crystals and are generally not suitable.

4. ***The relative amount of parent-daughter ratio in the crystal is known at its formation.***

The ratio of daughter isotope to the non-radiogenic isotope is a constant in its chemical mixture to begin with. Comparing the two ratios of radioisotopes to Pb-204 will enable us to create a graph known as an *Pb-Pb isochron* graph. From this graph, the gradient can reveal the time that the sample was formed.

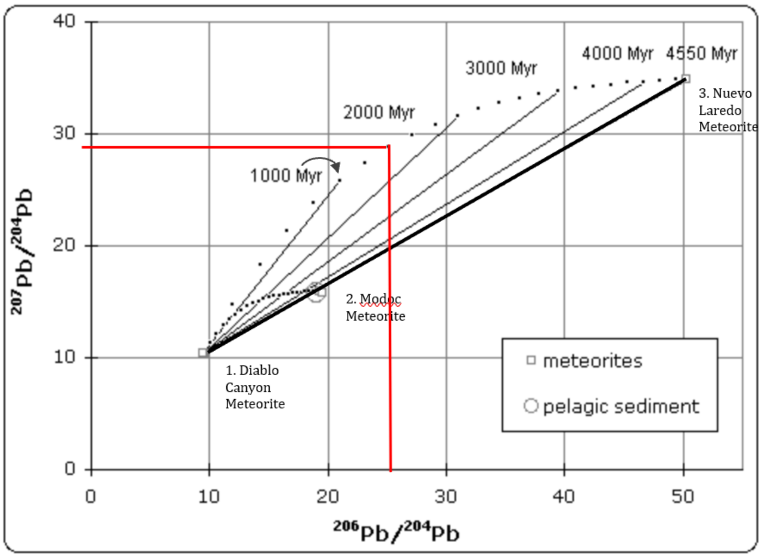


Figure 1: Original Isochron graph of Pb-Pb for collected meteorites and ocean floor sediment.

The Pb-Pb Isochron in Figure 1 represented a major breakthrough in the use of lead isochrons when it was published in 1956. It presented the analysis of three stony meteorites and showed that they fell on the same isochron. In addition, it showed that a sample of modern ocean (pelagic) sediment fell on the same isochron. Besides offering confirmation of the meteorite age that had been approached in many studies, it offered evidence that meteorites and the Earth are closely related and of the same age. It used a lead rich mineral from the Canyon Diablo meteorite as the standard. The isochron age was initially reported as 4.55 Gyr in 1956, but that became 4.50 Gyr with the application of the revised half-lives for the lead isotopes involved.

For questions (b), (c) and (d), make explicit reference to the relevant assumptions (provided on the previous page) used in radiometric dating to answer the questions below.

General marker's comment: The statement above was largely ignored by most students in addressing parts (c) and (d)

(b) State and explain which two rock types cannot be used and the most ideal rock type that can be used for isochron dating.

(3 marks)

Description	Total
Cannot be metamorphic rock (assumption 1) as daughter or parent atoms can leak in and out of the rock	1
Cannot be sedimentary (assumption 3) as there are two many varieties of crystal present	1
Must be old igneous rock as young igneous rock (assumption 3) has not had enough time for the ratio to be established.	1
Total	**3**
Quite poorly responded to. The most common issue was not fully justifying selections and many students weren't able to identify the most ideal type of rock. No marks awarded if incorrect reasoning provided. Half a mark awarded for incorrectly stating *all* igneous rocks can't be used (if reasoning provided and explained) Meteorites accepted as ideal if reasoning provided (double up of question c)	

(c) Explain why meteorites that fall to Earth can also be used to estimate the age of the Earth.

(2 marks)

Description	Total
Meteorites formed around the same time as the Earth during the formation of the solar system. (Or, evidence shows that they fall on the same isochron as ocean sediment)	1
Meteors in outer space can be considered a closed system and atoms cannot enter or leave it (satisfying assumption 1)	1
Total	**2**
Very few students received 2 marks for this question. There are two parts to this question. Why are they believed to be the same age? And why does the rock type satisfy the assumptions provided for isochron testing? Most students addressed only the first part or did not justify their responses. Stating "they are the same age" received no marks.	

(d) Explain why the estimate of the age of the Earth was revised from 4.55 Gyr to 4.50 Gyr.

(2 marks)

Description	Total
The estimate of the age of the Earth is based on a calculation involving the half life of lead isotopes (Assumption 2 states that the half life must be known)	1
These half life values were changed after 1956 which then changed the estimation of the age of the Earth.	1
Total	**2**
Again, few students gained 2 marks for this, stating only that the half life of lead isotopes had been revised. They did not explicitly state why this altered the estimate of the age or make explicit reference to an assumption.	

The bold line on the Isochron in figure 1 shows that the 3 stony meteorites and pelagic sediment all fall on a line which provides the currently accepted age of 4.50 Gy. The curved black dots show how the ratios of $^{207}Pb/^{204}Pb$ to $^{206}Pb/^{204}Pb$ change over time. Each black dot is a time interval of 200 million years (Myr).

Consider a sample of a stony meteorite that contained an initial measured ratio of $^{207}Pb/^{204}Pb$ to $^{206}Pb/^{204}Pb$ to be 10:10 (the start of the Pb-Pb isochron.)

(d) Use the isochron to estimate the $^{207}Pb/^{204}Pb$ to $^{206}Pb/^{204}Pb$ ratio after 1.4 Gyr.

(2 marks)

Description	Total
Lines are drawn in isochron to correct dot point.	1
ratio = 29:25	1
Total	**2**
About half the students were able to correctly interpret this. All questions involving interpretation of a graph require working lines to be drawn. Not only did you lost one mark for not showing this, you were unable to get any follow through marks if you misinterpreted the graph.	

A sample of U-235 was measured to have an activity of 1.45 mBq.

(e) Given the half of U-235 is 0.70 $\times 10^9$ years, calculate its activity 4.50 Gyr ago.

(3 marks)

Description	Total
$n = t / t_{1/2} = 4.50 / 0.70 = 6.43$	1
$A = A_0(1/2)^n$ $A_0 = A / (1/2)^n$	1
$= \dfrac{1.45 \times 10^{-3}}{(1/2)^{(6.43)}}$ = 0.125 Bq	1
Total	**3**
Mostly well done although several students incorrectly assigned A and A_0	

(e) Explain why the black dots curve away towards the horizontal.

(3 marks)

Description	Total
U-235 has a much shorter half-life (0.7 Gyr) compared to U-238 (4.47 Gyr)	1
Over time, less Pb-207 will be present in the sample compared to Pb-206	1
This will cause the Pb-207 values to lessen over time, causing the isochron to bend towards the x-axis.	1
Total	**3**
A common error was to discuss the half lives of Pb-207 and Pb-206 as opposed to the parent nuclei of U-235 and U-238. Many students did not fully explain their responses, gaining 2 out of 3 marks.	

End of Section Three